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ENERGY SECURITY: INVESTIGATING NATURAL GAS FOR ENERGY GENERATION AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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ABSTRACT

Reducing carbon-dioxide emissions that come from coal-fired power stations is a major challenge especially for developing countries. Renewable energy has reached and surpassed grid parity in many countries, however, due to the intermittent nature of solar and wind energy which are popular choices of renewable energy, energy storage becomes necessary to serve baseload energy requirements. The need for energy storage increases the cost of adopting renewable energy and in most cases makes the investment unfeasible. Furthermore, the spatial demands of renewable energy make it an unsuitable choice for many sites that have high baseload energy requirements such as airports. Emissions from natural gas-powered stations are half those of coal-fired power stations, therefore it is an attractive alternative in the quest for reducing carbon emissions in developing countries. This paper presents an investigation into natural gas as an energy source for airports in South Africa, providing a technical and financial evaluation (or technoeconomic assessment) of its adoption at airports.

KEYWORDS: Techno-Economic Assessments, Alternative Energy, Feasibility of Natural Gas for Airports, Natural Gas Installations, Combined Heat and Power, Natural Gas Trigeneration for Airports, Natural Gas Turbine & Natural Gas Internal Combustion Engines

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Original Article

INTRODUCTION

Natural gas is the cleanest of all fossil fuels and the main products of combustion of natural gas are carbon dioxide and water vapour. The combustion of natural gas releases small amounts of nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO), other reactive hydrocarbons and virtually no particulate matter [1]. For this reason, natural gas is a popular choice in replacing coal as a fuel source especially where space and cost is a limitation when considering renewable energy and its energy storage requirements.

Some airports in South Africa face the challenge of high baseload energy demand with limited space for renewable energy and the added cost of energy storage makes renewable energy unfeasible. Airports Company South Africa (ACSA) is South Africa's airport authority owning and operating nine airports in South Africa namely OR Tambo International Airport (ORTIA) (in Kempton Park, Gauteng), Cape Town International Airport (CTIA) (in the Western Cape), King Shaka International Airport (KSIA) (Durban, KwaZulu-Natal), Port Elizabeth International Airport (PEIA) (in the Eastern Cape), East London Airport (EL) (in the Eastern Cape), Bram Fischer International Airport (BFIA) (in Bloemfontein, Free State), George Airport (GG) (in the Eastern Cape), Upington International Airport (UPIA) (in the Northern Cape) and Kimberley Airport (KIM) (in the Northern Cape). Renewable energy can easily be incorporated into ACSA's six regional airports as their operational hours and

energy demands are low compared to its three busiest international airports, OR Tambo International Airport (ORTIA), (CTIA) and (KSIA).

ACSA's quest for reducing carbon emissions resulting from their electricity consumption has led to the installation of solar photovoltaic (PV) plants at PEIA, BFIA, GG, UPIA and KIM with a sixth solar PV plant at installation stage for EL. The same approach could not be adopted for ORTIA, CTIA and KSIA as the operating hours and extent of operations result in high baseload energy demand coupled with the fact that most of the available land has been reserved for commercial development and the addition of future capacity. Renewable energy also becomes unfeasible when considered in larger scales, especially with the energy storage required to smooth out intermittencies. Renewable energy technologies have low capacity factors.

The availability of natural gas close to ORTIA and KSIA as well as the establishment of virtual gas networks covering their geographical areas, including CTIA, makes natural gas an attractive alternative in the quest for reduction in carbon emissions resulting from the airports' grid electricity consumption. The Eskom load shedding and ageing power generation fleet coupled with increasing electricity tariffs make the search for alternative energy a business risk and an economic push for ACSA's international airports. Using natural gas to produce both electricity and recovery of heat for heating demands and to provide air conditioning (trigeneration or combined heat and power) is beneficial and energy efficient.

This study covers technology description, identification of technology type, typical components constituting the technology, assessment of technology maturity, cost benefit analysis that looks at the investment required, energy derived, feasibility indicators of the investment sensitivity analysis of using natural gas as an energy source for ORTIA, CTIA and KSIA. The study also presents the technology risk assessment, airports integration strategy and the proposed operational philosophy covering the technical aspects, plant operation for business continuity and for cost effectiveness as well as the operations and maintenance philosophies.

The key parameters for the natural gas-to-power technology to work successfully for airports are:

- Availability of natural gas supply in the region
- Effective integration of the technology into the airport environment

The key parameters for natural gas power plants to be adopted at airports owned and operated by ACSA are:

- It must prove to be economically feasible for the airports
- The technical and business risks of plant operations and plant related activity must be acceptable, this includes cost impact and implications
- The natural gas fuel supply must be guaranteed for the economic lifespan of the plant, and the supply capacity must be security backed with the ability to be increased

Description of the Technology

Natural gas is formed in the earth's crust as a result of transformation of organic matter due to heat and pressure of overlying rock. The gas hydrocarbons can also be produced as a result of microbial decomposition of organic substances and due to reduction of mineral salts. Some of these gases are released into the atmosphere or hydrosphere while the rest

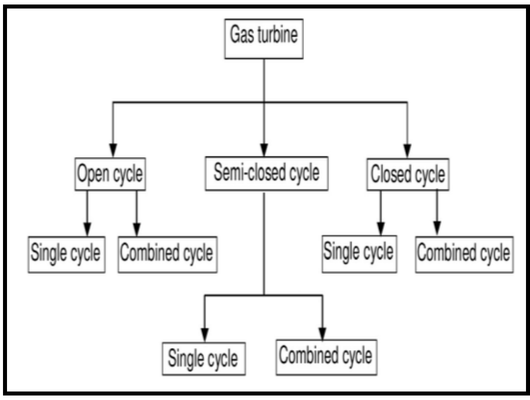
accumulates in the upper layers of the earth's crust. The composition of natural gas varies depending on a number of factors such as origin, location of deposit and geological structure. Natural gas mainly consists of saturated aliphatic hydrocarbons like methane. Components such as carbon dioxide, hydrogen sulphide, nitrogen and helium constitute an insignificant proportion of natural gas composition [1].

The natural gas extracted is available in different forms for commercial and industrial use. While liquefied natural gas (LNG) and compressed natural gas (CNG) are similar, their delivery and storage methods are different. LNG is frozen in order to turn it into liquid form, whereas CNG is pressurised to the point where it is very compact. LNG takes up less storage space on a vehicle than CNG, and it also offers an energy density that can be compared to diesel fuel. This makes it a common choice among many long-haul trucking companies. Using proper procedures, LNG can be converted to CNG. On the other hand, CNG is easier to refuel than LNG, which requires special handling and equipment. CNG is also very light, so if there is a leak, it will dissipate. It has an unlimited hold time, so even if it goes unused, there is no fuel loss. This makes CNG a safer choice over LNG. CNG also has lower production costs than LNG [2].

"CNG can be transported through pipelines. Some components need to be removed from the natural gas before CNG can be safely delivered. Also, while being processed, producers typically add an unpleasant smell (mostly ethanethiol), thus making natural gas easily recognisable in case of leaking. Like CNG, liquefied natural gas also occupies less space than it did in its gaseous state. Liquid gas can be 600 times denser than it was after extraction. Liquified natural gas can be transported in barrels. The process of creating LNG is more expensive, so the price of LNG is higher than CNG, but it is a great opportunity to transport natural gas over long distances effectively. Without pipelines, LNG is a great alternative as a power source." [3]

This technoeconomic assessment focuses on the use of natural gas for power generation and excludes its use for energy storage (such as natural gas powering fuel cells, etc) and vehicle fleets (cars, light delivery vehicles, etc., running on natural gas). Power can be generated by natural gas through its combustion in gas turbines (GT) or internal combustion engines (ICE) to produce electricity, and heat may also be recovered.

Natural gas turbines have various plant configurations as can be seen in Fig.1. A GT unit includes an air compressor, a combustor, and an expansion turbine. A typical gas turbine can be seen in Fig. 2. Gaseous or liquid fuels (in this case natural gas) are burned under pressure in the combustor, producing hot gases that pass through the expansion turbine, driving the air compressor. Fig. 3 shows the schematic of a closed cycle gas turbine (CCGT) [4].



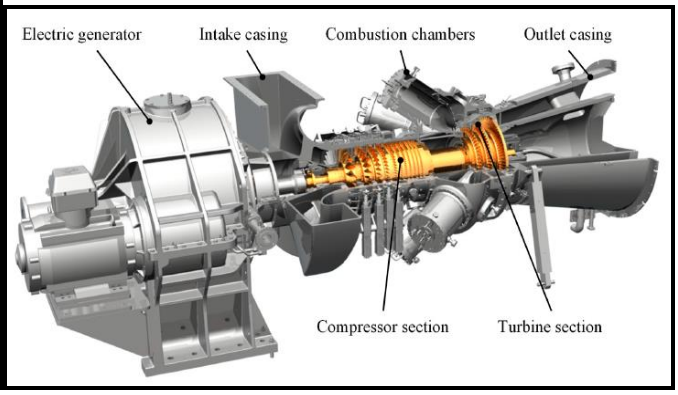
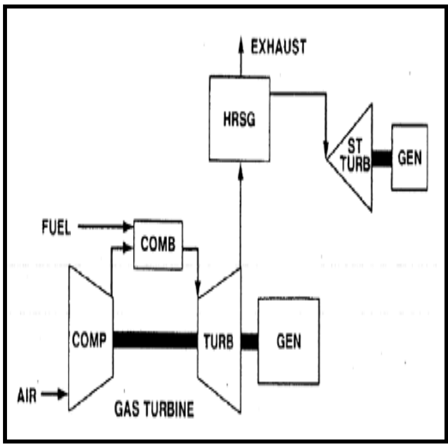


Figure 1: Classification of Gas Turbines based on Thermodynamic Cycles [5].

Figure 2: Typical Gas Turbine Construction [6]



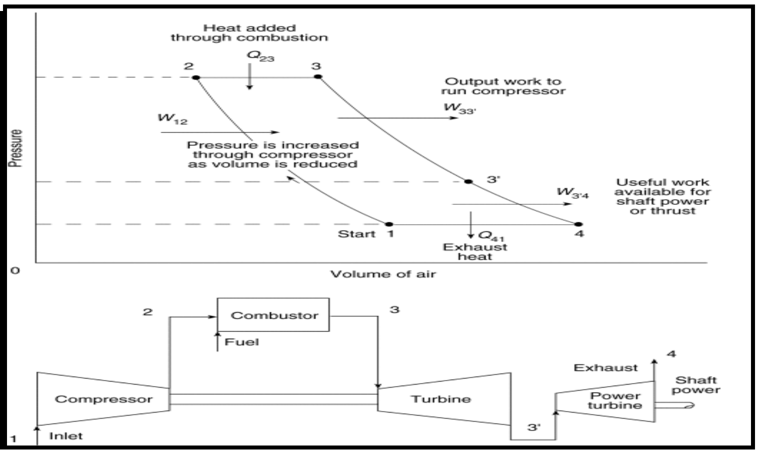
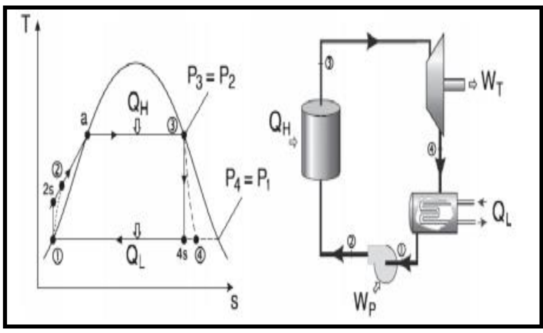


Figure 3: Simple Schematic of a Closed Cycle Gas Turbine (CCGT) [4]

Figure 4: Gas Turbines Thermodynamic Brayton Cycle for Open Cycle Gas Turbine (OCGT) [7].

The shaft of the GT is coupled to an electric generator which is driven by the mechanical energy produced by the GT. The hot exhaust gas exits the GT at temperatures of between 538 °C and 593 °C and passes through a heat recovery steam generator (HRSG) where it exchanges heat with water producing steam at two or three pressures and may incorporate a reheat loop. The exhaust gas is cooled to between 80 °C and 135 °C before exiting through the HRSG stack. Depending on the selected GT and its associated exhaust temperatures, the high-pressure steam conditions from the HRSG range anywhere between 4.32 MPa(g) and 17.23 MPa(g) with temperatures of 482 °C to 565 °C [4].

The steam produced in the HRSG is used to drive a steam turbine generator. In larger plants, it is common to have two or three GT/HRSG trains providing steam for a single large steam turbine. Usually about two-thirds of the total power is produced from the GTs and one-third from the steam turbine. The steam from the steam turbine is condensed using an air-cooled condenser or a closed-loop cooling tower, and the condensate is returned to the HRSG by condensate pumps. [4] The thermodynamic cycle in the gas turbine is the Brayton cycle (Fig. 4 shows the Brayton Cycle for an open cycle gas turbine) and in the steam turbine is the Rankine cycle (Fig. 5). “An OCGT is one in which the working fluid remains gaseous throughout the thermodynamic cycle. The main advantages of open cycle GTs include flexibility in siting, low emission levels with natural gas fuel, low capital cost, and short construction time. These advantages make them attractive for peaking duty applications. Peaking duty open cycle site arrangements can be designed to allow for later conversion to combined cycle through staged development.” [4]



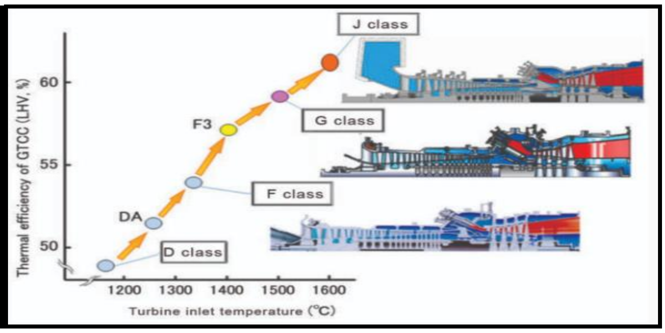
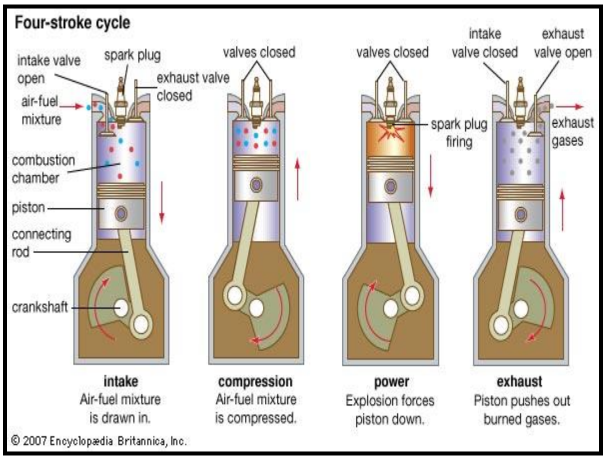


Figure 5: Steam Turbines Thermodynamic. Simple Rankine Cycle [8].

Figure 6: Development History of Mitsubishi Gas Engines [9]

There are various types and categories of GTs available in the market today. These include the earlier designed E- or lower-class turbine models, the state-of-the-art heavy-duty F-, G- and H-class turbine models, and the aeroderivative GTs that are generally used in power, combined heat and power (CHP), and industrial applications. These GTs are available in given sizes or ratings. Their efficiencies are strongly influenced by several factors such as inlet mass flow, compression ratio, and expansion turbine inlet temperature. The earlier design of heavy-duty GTs had maximum turbine inlet temperatures ranging anywhere between 815 °C and 1093 °C. More recent state-of-the-art heavy-duty GT designs have turbine inlet temperatures that reach 1315 °C to 1371 °C. These turbines are designed with innovative hot gas path materials and coatings, advanced secondary air cooling systems, and enhanced sealing techniques that enable higher compression ratios and turbine inlet temperatures. The advancements made in the newer GTs by the manufacturers are generally adopted into the earlier models for efficiency and power output improvements. Fig. 6 shows the development history of Mitsubishi gas engines. Combined cycle plants can operate with both conventional and advanced GTs. With GTs running at higher turbine inlet temperatures that result in higher exhaust temperatures, it is possible to include a reheat stage in the steam turbine. This further increases the efficiency in the bottoming cycle [4].

Natural gas power plants can also produce electricity through an internal combustion engine (ICE) which is popular with smaller power plants serving specific commercial businesses or small industrial sites. They are usually used in a combined heat and power (CHP) plant that primarily produces electricity with the heat of the ICE being recovered to be used either for plant heating or site heating processes. For commercial sites, natural gas trigeneration plants are popular in that the natural gas powered ICE engine is adopted to produce electricity, the heat is recovered to produce hot water or steam that powers an absorption chiller which provides space air conditioning (heating and cooling), and remaining heat is used to satisfy water heating demands or used for process heating purposes. The Otto cycle is the thermodynamic cycle that takes place in a four-stroke spark ignition internal combustion engine. Fig. 7 and Fig. 8 show the four stroke and Otto cycles respectively.



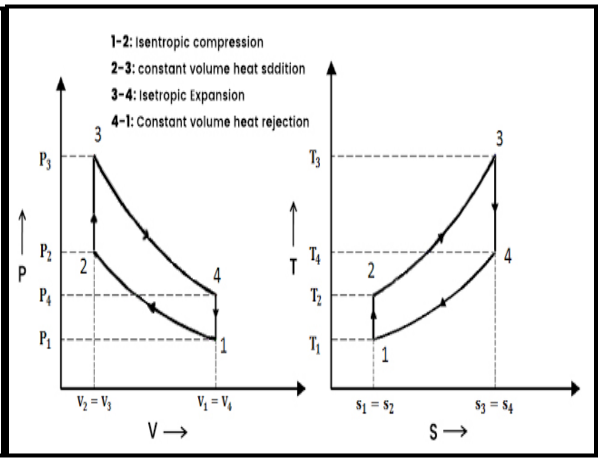


Figure 7: Spark Ignition Internal Combustion Engine (ICE) Working [10]. Figure 8: P-V and T-S Diagram of the Otto Cycle [11]

Internal combustion engines in large, stationary power generation applications are 4-stroke, spark-ignited (SI) engines. Natural gas is supplied to the engine through a gas-regulating unit that filters the gas and regulates the pressure. The maximum pressure needed by large engines is approximately 4.5 bar (absolute). Many gas supply networks have a natural gas pressure sufficient to supply engine-generators without the need for natural gas compressors. The four strokes

in a power cycle are intake, compression, expansion, and exhaust stroke. Small natural gas engines typically use natural aspiration for their air-intake. Large natural gas engines have a turbocharger to boost air flow. The turbocharger utilises exhaust gas energy in the expansion turbine to drive the air compressor. With more air flow comes more fuel, resulting in higher output. Compression ratios in the large bore engine class are in the range of 11:1 to 12:1. The compression ratio is limited since a higher compression ratio could lead to auto-ignition of the fuel which can damage the engine (knock) [4].

One of the key decisions that ACSA has to take is the technology choice for the adoption of natural gas power generation at the airports. Many factors must be considered that take into account the costs (operational, capital expenditure, maintenance, risks, insurance and the cost of doing business), and fuel availability and security for the duration of the economic lifespan of the natural gas power plants. Table 1 provides the technical comparison of gas turbines and internal combustion engines.

Table 1: Technical Comparison of the Operation of Gas Turbines and Internal Combustion Engines [12]

	Dimension of Comparison	Gas Turbines (GT)	Internal Combustion Engines (ICE)	Advantage to GT or ICE
1	Start-up time	Combined cycle gas turbines can take over 30 minutes to start.	Combustion engine power plants can start and reach full load in less than 10 minutes, providing flexible, quick-start capability.	ICE
2	Advantages of modularity	Modularity in architecture provides limited operational modularity for gas turbines due to the size of units, limited number of units, and efficiency trade-offs for simple cycle versus combined cycle.	Combustion engine power plants comprised of multiple generating units complement renewable energy without sacrificing efficiency.	ICE
3	Part load efficiency and flexibility	Gas turbine manufacturers boast efficiencies of 55 % or greater, at full load, dropping to below 50 % between 55 % to 65 % of full load and less than 30 % efficiency at half load. Operation at partial load and turndown limitations can restrict the flexibility of CCGT plants.	Combustion engine power plants do not have minimum load limitations and can maintain high efficiency at partial load due to modularity of design s load is decreased, individual engines within the generating set are shut down to reduce output. The engines that remain operating can generate at full load, retaining high efficiency of the generating set.	ICE
4	Pulse load efficiency and profitability	For short duration pulse load needed to balance solar and wind output, gas turbines are not profitable.	Combustion engine power plants offer significant advantages over gas turbines, with higher pulse load efficiency and the capability to provide ultra-flexible and cost-efficient output.	ICE
5	Derating due to ambient temperature	Gas turbines in particular can experience significant performance derating in hot, humid conditions.	Combustion engines are less sensitive to temperature and humidity, outperforming gas turbines in hot conditions.	ICE
6	Ramp rate	Ramp rates of most industrial frame gas turbine models are advertised as 10 MW/min up to 100 MW/min, with an average of about 25 MW/min.	Combustion engines can ramp at over 250 MW/minute, much faster than gas turbines, providing ultra-responsive power that is needed to integrate renewable energy.	ICE

7	Fuel flexibility	While gas turbines are often advertised as having fuel flexibility, about 90 % of gas turbines worldwide operate on natural gas or liquefied natural gas (LNG) because of its purity and ease of combustion. Gas turbines require about 10 minutes to switchover from baseload gas to fuel oil.	Combustion engine maintenance is not affected by fuel type as the engines are not sensitive to metals or salts in fuel oils. They are able to switch from natural gas to fuel oil instantaneously. They are also able to operate in fuel sharing mode burning varying percentages of gaseous and liquid fuels simultaneously.	ICE
8	Water consumption	A combined cycle gas turbine power plant (CCGT) with a recirculating system will consume approximately 780 litres/MWh.	Combustion engine power plant operating in simple cycle on natural gas will consume a mere 3 litres/MWh. This is due to the high efficiency and low cooling needs.	ICE

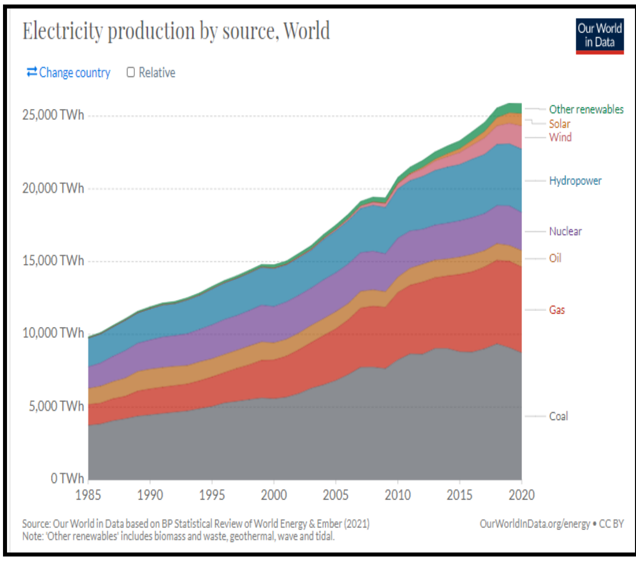
The technology to be adopted will be decided upon in the next stage of the project cycle, i.e., the feasibility and front-end engineering design (FEED) study (FEL 3), considering the technical dimension given in Table 1.

Assessment of Technology Maturity

"John Barber was granted the world's first gas turbine patent, in 1791 in England, for his design that used the thermodynamic cycle of the modern gas turbine but obviously not the similar components. In 1903, Norwegian engineer Aegidius Elling successfully designed and built the first simple cycle gas turbine with a net power output of 8.1 kW and turbine inlet temperature of 400 °C. During the same time when Elling's work was in progress, Franz Stolze, a German engineer who got patent in 1899 for his gas turbine that was designed in 1873, was installing world's first complete axial design GT at Berlin-Weissensee Power Station in Germany and tested it in 1905. Another gas turbine of historical importance, developed by Charles Lamale and Rene Armengaud and designed by French engineer August Rateau in 1905-1906. In 1920s and 1930s considerable amount of efforts were made at BBC (later ABB and now Alstom Power) in developing efficient axial compressors. The world's first successful electric power generating gas turbine consisting of a single shaft design with a 23 stage axial compressor, one single can combustor and a seven stage axial turbine, developed by BBC went into commercial operation in Neuchatel, Switzerland in 1939." [13]

The use of natural gas for electricity generation is not a new concept, but a tried and tested, mature technology in use around the world. There are more than 130 major natural gas to power plants installed in the world ranging from 55 MW in Australia (Barcaldine Power Station) to 5.6 GW in Russia (Surgat-2 Power Station) [14].

Natural gas has gained popularity over the last two and a half decades as a choice for electricity production with oil and coal sources being somewhat at a lower growth rate in terms of use for electricity. This could be owing to price fluctuations of oil and the carbon footprint associated with coal. In the light of climate change natural gas is the preferred fuel for efficiency and reduction in carbon dioxide emissions associated with electricity generation (figure 9). South Africa has been growing their uptake of natural gas over the last decade and a half (figure 10). The gas turbine market is dominated by North America and the Asia Pacific (figure 11).



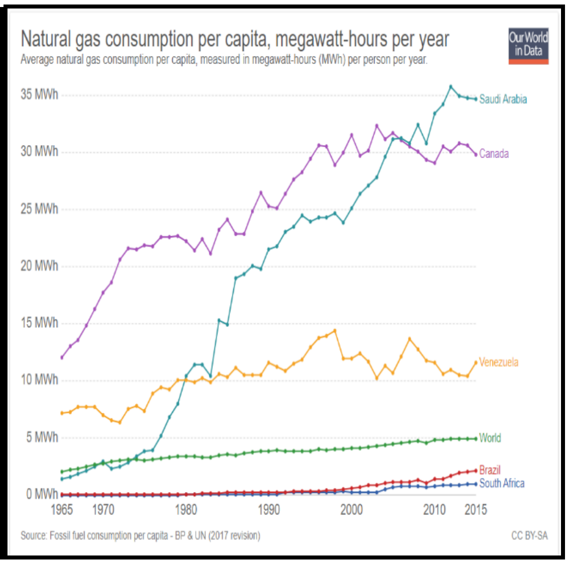


Figure 9: Growing Trend of use of Natural Gas. Figure 10: South Africa Appearing on the Trend of to Produce Electricity [15] Natural Gas Consumption [16].

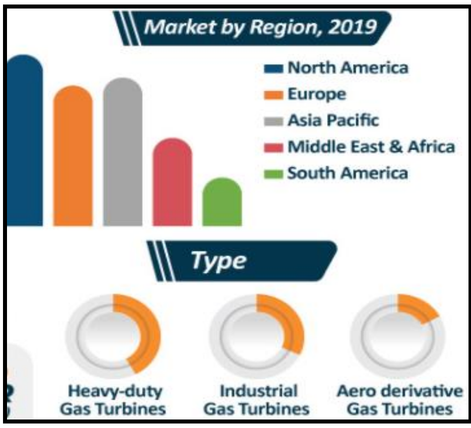


Figure 11: Gas Turbine Market Share [17]. Figure 12: Sasol Natural Gas Power Plant [19].

Reciprocating internal combustion engines are a well-established and widely used technology. Worldwide production for reciprocating internal combustion engines is over 200 million units per year. Reciprocating engines include both diesel and spark-ignition configurations. The long history of technical development and high production levels have contributed to making reciprocating engines a rugged, reliable, and economic choice as a prime mover for CHP applications. Reciprocating engine technology has improved dramatically over the past three decades, driven by economic and environmental pressures for power density improvements (more output per unit of engine displacement), increased fuel efficiency, and reduced emissions. There are over 2 000 active reciprocating engine combined heat and power (CHP) installations in the U.S. providing nearly 2.3 GW of power capacity. These systems are predominantly spark ignition engines fuelled by natural gas and other gaseous fuels (biogas, landfill gas). Natural gas is lower in cost than petroleum based fuels and emissions control is generally more effective using gaseous fuels. Reciprocating engine CHP systems are common in universities, hospitals, water treatment facilities, industrial facilities, and commercial and residential buildings. Facility capacities range from 30 kW to 30 MW, with many larger facilities comprised of multiple units. Spark ignited engines fuelled by natural gas or other gaseous fuels represent 84 % of the installed reciprocating engine CHP capacity.

Current natural gas engines for power generation offer low first cost, fast start-up, proven reliability when properly maintained, excellent load-following characteristics, and significant heat recovery potential. Natural gas is the predominant spark ignition engine fuel used in electric generation and CHP applications. Dual fuel engines are predominantly fuelled by natural gas with a small percentage of diesel oil added. There are two main configurations for introducing the gaseous fuel in a dual fuel engine. These engines can be purpose built or conversions of diesel engines. Such engines can be switched to 100 % diesel operation. Dual fuel engines provide a multi-use functionality. Operation on predominantly cheaper and cleaner burning natural gas allows the engine to be used in CHP and peak shaving applications, while operation on 100 % diesel allows the engine to also meet the onsite fuel requirements of emergency generators. The dual function adds benefit in applications that have specific emergency generator requirements such as in hospitals or in public buildings [18].

In South Africa, the largest natural gas powerplant is owned by Sasol. The 140 MW plant is located at Sasolburg, South Africa. It was commissioned in December 2012 and has been fully operational from July 2013. [19] Newcastle Energy own an existing 18.5 MW capacity gas fired co-generation plant within the Karbochem Industrial Complex in Newcastle, KwaZulu-Natal. Through the Newcastle Gas Engine Power Plant (NGEPP) Independent Power Producer (IPP) project, Newcastle Energy proposes to increase its electricity generation capacity, within the same site, to approximately 100 MW [20].

Avon Peaking Power (Avon) is an energy generating facility that is located in Shakaskraal, in the province of KwaZulu-Natal, owned by Avon Peaking Power (RF) Pty Ltd. Avon is a 670 MW greenfield OCGT facility that is privately owned. It was built and funded by the owner, and then endorsed by the Department of Energy (DoE). It solely supplies power to Eskom under a 15 year power purchase agreement (PPA). The facility supplies electricity to the national grid during peak demand hours as well as during emergency situations. In addition to its generating capabilities the facility can also be used to regulate network voltage fluctuations, that is, to stabilise the grid. Avon is located adjacent to an existing high-voltage Eskom substation with the electricity being fed into the transmission system at 275 kV. [21] There are other power plants in South Africa using gas turbine generators, fuelled by diesel oil and other fuels.

Dedisa Peaking Power (Dedisa) plant is a facility owned by Dedisa Peaking Power (RF) Pty Ltd. It performs the same function as the Avon peaking plant but is 335 MW, located in the Coega Industrial Development Zone (IDZ) in Port Elizabeth [22]. East London in South Africa is home to Eskom's Port Rex Power Station, a 171 MW power plant consisting of three 57 MW gas turbine generators, which is critical for system voltage stability in the Eastern Cape. The station can be operated by remote control from Eskom's National Control Centre at Simmerpan to provide back-up and black-start. [23]

The Western Cape in South Africa has three power stations running with gas turbine generators. Acacia Power Station consists of three 57 MW gas turbine engines at an installed capacity of 171 MW and provides back-up electrical supply to Koeberg Nuclear Power Station as per National Nuclear Regulator licensing requirement [24]. Ankerlig Power Station is a 1 327 MW gas turbine plant consisting of nine OCGT generating units running on fuel oil (diesel) [25], the Gourikwa Power Station is 740 MW and consists of five units [26].

There is a 2 MW natural gas trigeneration plant operating in Fairland, Gauteng owned by mobile telecommunications operator MTN which powers a building housing a data centre and a test switch centre at its head office campus. The trigeneration plant is powered by methane gas, which is piped over 800 km from Sasol's Mozambique gas fields to Egoli Gas in Johannesburg, and then to the company's office, MTN South Africa. The 400 ºC exhaust gas is sent

through lithium bromide absorption chillers to cool water, which MTN uses for the cooling needs in the building. The plant consisted of two 1 MW General Electric Jenbacher gas engines, and the absorption chillers were supplied by Carrier [27].

The MTN trigeneration plant was visited by the ACSA technical team in an effort to understand how the plant operates and serves the energy needs of the buildings at the MTN head office in Fairways. This plant setup, fuel supply and energy distribution (electricity, chilled water and heat) is what ACSA is considering in the investigation of the adoption of natural gas as a fuel supply for the three airports, ORTIA, CTIA and KSIA.

Cost Benefit Analysis

Due to this technoeconomic assessment being a desktop exercise meant to provide an indication of the economics of the adoption of natural gas fuel trigeneration plants for airports at pre-feasibility (FEL 2 or Front-End Loading Stage 2), factors such as the cost of fuel gas supply logistics, the savings and benefits of using air conditioning and heat are excluded. The capital cost of the plant was based on the MTN trigeneration plant cost.

(a) Rationale for the Scale of Natural Gas to Power

The rationale for the selection of the size of electrical generators using natural gas power lies in the conceptualisation of the energy mix for the airports towards zero carbon emissions. Figures 17, 18 and 19 show the electrical demand approximated for ORTIA, CTIA and KSIA respectively in 2018. The total electrical demand for ORTIA is 16 MVA, for CTIA is 10.5 MVA and for KSIA is 5.7 MVA. Conceptualising the energy mix for the airports, shows that the plan is that when full electrical demand occurs (16 MVA for ORTIA, 10.5 MVA for CTIA and 5.7 MVA for KSIA), the critical load will be supplied by the national electricity grid. For ORTIA and CTIA, this critical load forms about 50 % of the baseload which is about 25 % of the total electrical demand. KSIA's baseload is about 45 % of the total energy demand, with the critical load being 20 %.

The remainder of the baseload at the airports were considered to be supplied from a lower carbon energy source other than the national electricity grid (alternative energy source). HVAC chiller loads forming part of the fluctuating load currently consuming electricity were considered to be changed to heat demand (renewable or waste heat) through the use of absorption chillers. The remainder of the fluctuating electrical load was considered to be supplied by renewable energy such as solar energy and wind energy.

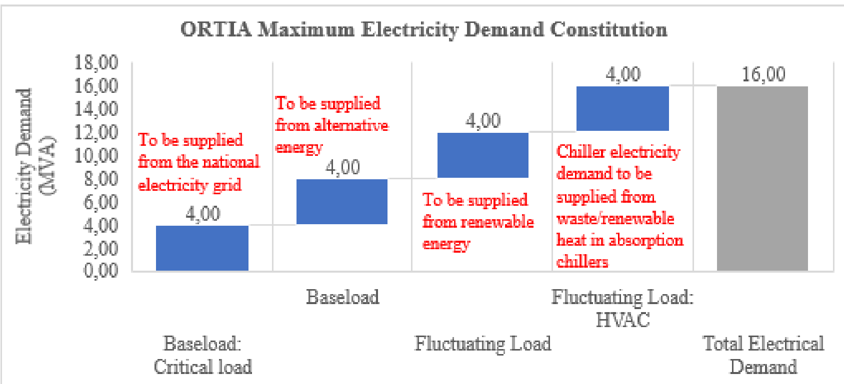


Figure 13: ORTIA Maximum Electrical Demand and Concept Plan for Energy Security.

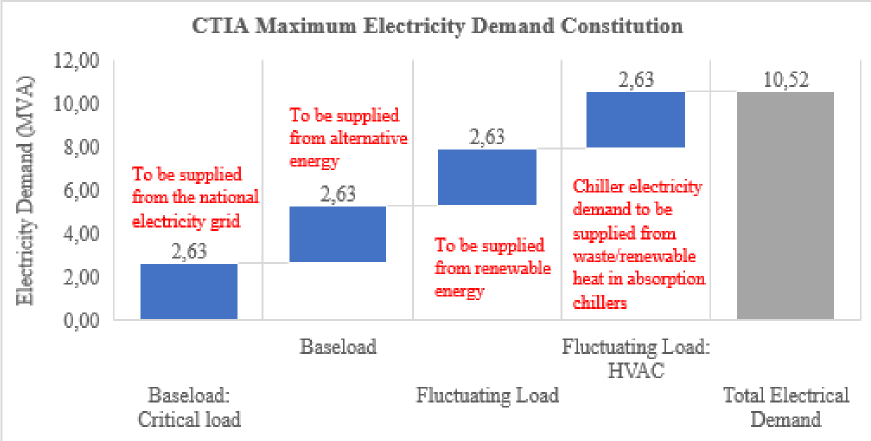


Figure 14: CTIA Maximum Electrical Demand and Concept Plan for Energy Security.

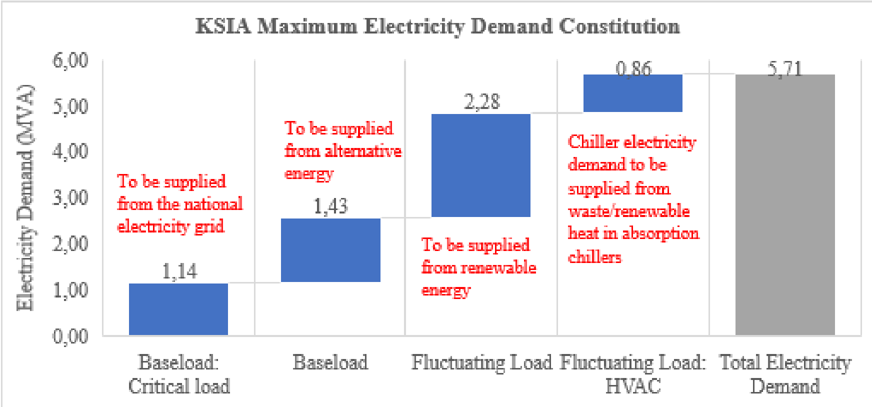


Figure 15: KSIA Maximum Electrical Demand and Concept Plan for Energy Security.

The focus in this paper is using natural gas as an alternative energy source to power the airports' baseload energy supply. For the fluctuating load, the renewable energy considered for the airports were solar photovoltaic (PV) plants. Solar PV was considered for investigation as the renewable energy option due to its ease of incorporation, familiarity to ACSA airports' operating environment and the availability of sufficient solar irradiation at all three locations. Natural gas was selected due to its availability in the three geographical regions, its maturity in the market and its high capacity factor.

Following the conceptual energy mix summarised in Fig. 13, 14 and 15, a FEL 2 (prefeasibility study) was performed on the energy sources proposed. Space availability for the solar PV plants was taken into consideration due to the land limitations that ORTIA, CTIA and KSIA face as growing airports where land is reserved for commercial and operational development. The capacity of solar PV plants needed to satisfy the fluctuating load was quite demanding in terms of spatial constraints. When compared to the option of increasing the capacity of the natural gas generator to rather serve the fluctuating load, such an investment seems like a better option. Refer to Tables 2, 3 and 4 for ORTIA, CTIA and KSIA respectively.

Table 2: Rationale for ORTIA's Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and Capital Expenditure (2018 basis)	**Fluctuating load:** **Solar PV 4 MW nominal power output which is 21 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), the project capital = ZAR 510m (2018 basis) **Baseload:** **Gas-to-power 4 MW nominal power output which is 5.25 MW installed capacity at 76 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)	**Fluctuating load:** **Solar PV 750 kW nominal power output which is 4 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 97m (2018 basis) **Baseload** **Gas-to-power 7.25 MW nominal power output which is 10.5 MW installed capacity at 69 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 230m (2018 basis)	**Baseload and fluctuating load:** **Natural gas generator 8 MW nominal power output which is 10.5 MW installed capacity at 76 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 230m (2018 basis)
Operational expenditure parameters used (2018 basis)	• **Solar PV:** Fixed operations and maintenance cost – ZAR 331 /kW-year; • **G2P:** Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)		
Macro-economic parameters used (2018 basis)	• Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years		

Table 3: Rationale for CTIA's Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and capital expenditure (2018 basis)	**Fluctuating load:** **Solar PV 2.63 MW nominal power output which is 13.8 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 335m (2018 basis) **Baseload:** **Gas-to-power 2.63 MW nominal power output which is 3.5 MW installed capacity at 75 % CF** • At ZAR 18k /kW (2015 end of job cost	**Fluctuating load:** **Solar PV 1.9 MW nominal power output which is 10 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 243m (2018 basis) **Baseload** **Gas-to-power 3.36 MW nominal power output which is 5.25 MW installed capacity at 64 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW	**Baseload and fluctuating load:** **Natural gas generator 5.26 MW nominal power output which is 7 MW installed capacity at 75 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 153m (2018 basis)

	of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)	natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)	
Operational expenditure parameters used (2018 basis)	• **Solar PV:** Fixed operations and maintenance cost – ZAR 331 /kW-year; • **G2P:** Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)		
Macro-economic parameters used (2018 basis)	• Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years		

Table 4: Rationale for KSIA's Gas-to-Power Plant Sizing

	Energy Mix Concept	Energy Mix Concept with Spatial Constraints Applied	Optimised Energy Mix Concept
Energy generating plant sizes and Capital Expenditure (2018 basis)	**Fluctuating load:** **Solar PV 1.43 MW nominal power output which is 7.25 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 182m (2018 basis) **Baseload:** **Gas to Power 2.28 MW nominal power output which is 3.5 MW installed capacity at 65 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)	**Fluctuating load:** **Solar PV 1.9 MW nominal power output which is 10 MW installed capacity at 19 % CF** • At ZAR 21k /kW (2015 end of job cost of the George Airport solar PV plant), project capital = ZAR 243m (2018 basis) **Baseload:** **Gas to Power 1.81 MW nominal power output which is 3.5 MW installed capacity at 52 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 77m (2018 basis)	**Baseload and fluctuating load:** **Natural gas generator 3.71 MW nominal power output which is 5.25 MW installed capacity at 71 % CF** • At ZAR 18k /kW (2015 end of job cost of the MTN 5.25 MW natural gas trigeneration plant), project capital = ZAR 115m (2018 basis)
Operational expenditure parameters used (2018 basis)	• **Solar PV:** Fixed operations and maintenance cost – ZAR 331 /kW-year; • **G2P:** Fixed operations and maintenance cost – ZAR 175 /kW-year; Variable operations and maintenance cost – ZAR 23.2 /MWh; Fuel – ZAR 135 /GJ (based on Sasol rates)		
Macro-economic parameters used (2018 basis)	• Discount rate: 11.5 %, Corporate tax rate: 28 %, Economic life: 20 years		

The nominal capacities of the natural gas-to-power technologies thus take on the fluctuating demand at smaller engine sizes for each of the international airports. The resulting installation capacity for each installation investigated for feasibility is 10.5 MW, 7 MW and 5.25 MW for ORIA, CTIA and KSIA respectively. Full details are provided below.

(b) Feasibility Study Results

Airports Company South Africa has an economic modelling department that creates economic models in excel spreadsheets. The economic model yields the net present value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA's 11.5% weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive it is an investment that pays itself off during its economic lifespan. The net present value (NPV) equation used in the economic model is given below, Equation (1), where the internal rate of return (IRR) is the return (*i* in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index (PI) provided in Equation (2) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+i)^t} \qquad \text{Equation (1)}$$

Where: $R_t =$ net cash inflows – outflows during a single period *t*

- *i* = discount rate or return that could be earned
- *t* = number of time periods

$$PI = \frac{PV\ of\ future\ cash\ flows}{Initial\ Investment} \qquad \text{Equation (2)}$$

Tables 5, 6 and 7 show the economic model inputs and outputs. In summary:

- OR Tambo International Airport – For a 10.5 MW natural gas-powered plant, the NPV is ZAR 347.75m (positive) and IRR of 22.8 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.
- Cape Town International Airport – For a 7 MW natural gas-powered plant, the NPV is ZAR 226m (positive) and IRR of 22.6 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.
- King Shaka International Airport – For a 5.25 MW natural gas-powered plant, the NPV)is ZAR 87.29m (positive) and IRR of 17.7 % (exceeding the ACSA WACC rate of 11.5 %) which shows that the installation is feasible.

Table 5: O R Tambo International Airport Economic Inputs and Outputs

Inputs		Output	
MW natural gas powerplant rated capacity	10.5	End of job cost	ZAR 230m
Capital cost (2018 basis)	ZAR 230m	Net present value	ZAR 347.75m
Electricity saving at beneficial operation	70 080 000 kWh/annum	Internal rate of return	22.8 %
Electricity cost (2018)	ZAR 1.47 /kWh	Nominal payback period	6 years
Beneficial operation	2020	Profitability index	2.6
Construction period	2 years		

Corporate tax	28 %	
Economic lifespan	20 years	
Operational and maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ	
Eskom tariff escalation	5.1 % per annum	
CAPEX escalation factor	1.05	

Table 6: Cape Town International Airport Economic Inputs and Outputs

Inputs		Output	
MW natural gas powerplant rated capacity	7	End of job cost	ZAR 153m
Capital cost @ 2018	ZAR 153m	Net present value	ZAR 226m
Electricity saving at beneficial operation	46 077 600 kWh/annum	Internal rate of return	22.6 %
Electricity cost (2018)	ZAR 1.47 /kWh	Nominal payback period	6 years
Beneficial operation	2020	Profitability index	2.56
Construction period	2 years		
Corporate tax	28 %		
Economic lifespan	20 years		
Operational and Maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ		
Eskom tariff escalation factor	5.1 % per annum		
CAPEX escalation factor	1.05		

Table 7: King Shaka International Airport Economic Inputs and Outputs

Inputs		Output	
MW natural gas powerplant rated capacity	5.25	End of job cost	ZAR 115m
Capital cost @ 2018	ZAR 115m	Net present value	ZAR 87.29m
Electricity saving at beneficial operation	32 499 600 kWh/annum	Internal rate of return	17.7 %
Electricity cost (2018)	ZAR 1.29 /kWh	Nominal payback period	8 years
Beneficial operation	2020	Profitability index	1.81
Construction period	2 years		
Corporate tax	28 %		
Economic lifespan	20 years		
Operational and maintenance cost (2018 terms)	Fixed: ZAR 175 /kW-year; Variable: ZAR 23.2 /MWh; Fuel: ZAR 135 /GJ		
Eskom tariff escalation factor	5.1 % per annum		
CAPEX escalation factor	1.05		

This prefeasibility study (FEL 2) conducted for the three selected airports show that all three natural gas trigeneration plant installations are feasible, i.e., ORTIA, CTIA and KSIA. To determine the factors that the prefeasibility would be most susceptible to, a sensitivity analysis was done.

(c) Sensitivity Analysis

For the sensitivity analysis, the four factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of the impact that each parameter had on the profitability relative to each other. The base cases used are described in table 5, Table 6 and table 7 for ORTIA, CTIA and KSIA respectively.

The profitability of the investment relies on the capital cost of the installation, the cost of electricity from Eskom, the operations and maintenance cost, and the fuel (feedstock) cost of the natural gas trigeneration plants. The effect that these four factors have on the NPV of the installations can be seen in Fig. 16, figure 17 and figure 18.

A 10 % increase or a 10 % decrease in the capital expenditure, electricity tariff, feedstock and operations and maintenance (O&M) cost shows that the electricity tariff is the most significant factor and the O&M cost the least significant factor in the feasibility of the natural gas trigeneration plant installation investments for ORTIA, CTIA and KSIA. A 10 % increase in the electricity tariff results in an increase in the NPV of ZAR 115.4m for ORTIA; ZAR 75.9m for CTIA and ZAR 47m for KSIA, however a 10% decrease in the electricity cost shows a decrease in NPV of ZAR 115.4m for ORTIA; ZAR 75.9m for CTIA and ZAR 47m for KSIA. A 10 % change in the feedstock cost has just over 50 % of the effect that the electricity tariff has the NPV. These results tell us that we should monitor the electricity tariffs of the airports closely as a change will affect the feasibility of the investment.

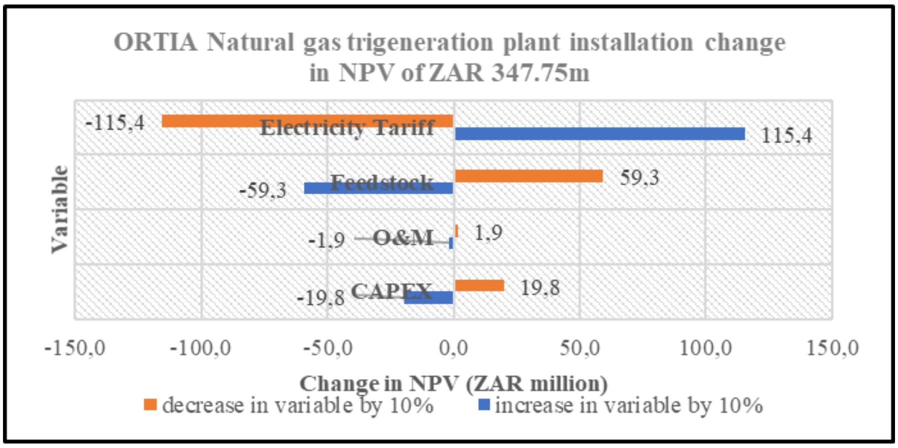


Figure 16: Sensitivity Analysis of the ORTIA Natural Gas Trigeneration Plant Installation.

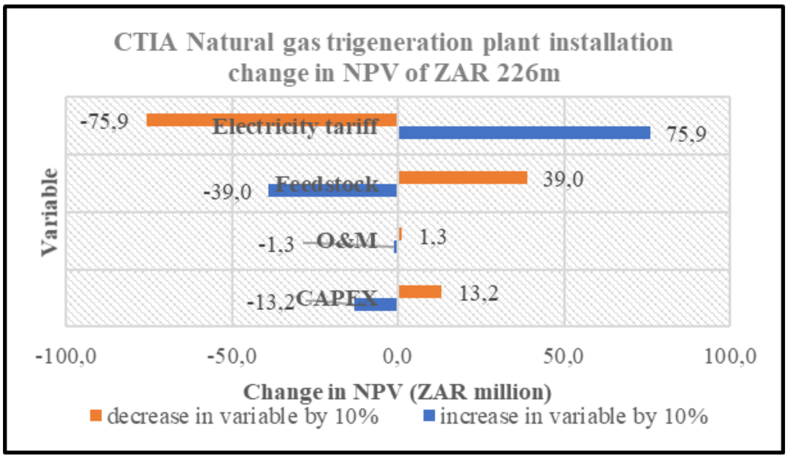


Figure 17: Sensitivity Analysis of the CTIA Natural Gas Trigeneration Plant Installation.

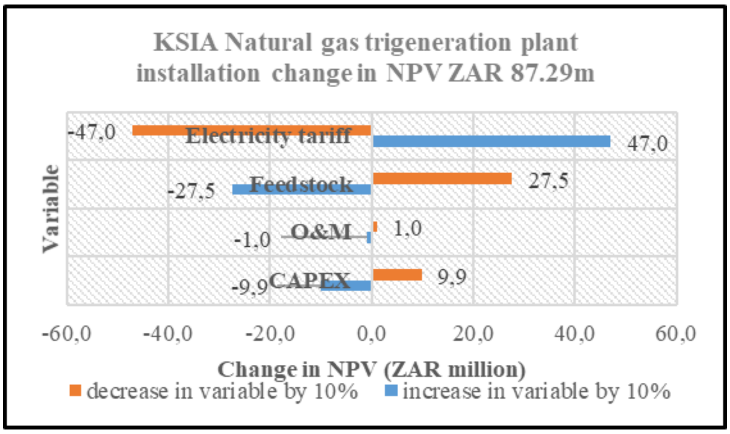


Figure 18: Sensitivity Analysis of the KSIA Natural Gas Trigeneration Plant Installation.

The results also show that the feasibility is sound in that even a 10 % change in the electricity, capital expenditure required, or operational expenditure required will not make the investment into natural gas trigeneration powerplants for ORTIA, CTIA and KSIA unfeasible.

Technology Risk Assessment

The natural gas powerplant technology being used as a baseload SOURCE of energy for ORTIA, CTIA and KSIA must be always available. The fluctuating load portion that the natural gas powerplant is meant to serve requires that the plant be able to respond to the varying energy demands efficiently and effectively. Table 8 performs a technology risk assessment and provides the possible mitigations.

Table 8: Technology Risk Assessment for the Natural Gas Power Plant for ORTIA, CTIA, KSIA

Risk	Description	Possible Mitigation
Feedstock supply	Natural gas supply is primarily from Sasol. Should their contract with Mozambique be terminated in 2028, alternative suppliers of natural gas will need to be acquired.	• Alternative suppliers of natural gas should be identified. • Adopt combustion engines that can use more than one type of feedstock.
Single point of failure	This is failure at a single point which, without, the entire plant will not generate electricity or heat for air conditioning or hot water. The failure of the natural gas engine is the single point of failure.	• Modularity must be introduced such that should a failure occur in one engine, the rest of the engines will be able to supply the energy demand. • Control systems must be employed to ensure that this transition is smooth and there is no impact on airport operations.
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	• Adopt natural gas engines that have a high ramp rate and are able to respond to varying energy demand effectively. • Ensure that controls are tested during commissioning to guarantee the system's ability to respond to varying demand without causing damage to infrastructure or negatively impacting airport operations.
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased to suit operational demand and work effectively for the purposes of maintenance towards cost effectiveness.	• Understand the demand profile of the airport's electricity, air conditioning and water heating requirements and apply the appropriate scale for the airport based on plant utilisation of the electricity and hot water generated. • Consider economies of scale for total plant design capacity and modular operations for the various demand requirements at every hour in the 24-hour day

5. Airports Integration Strategy

The natural gas power plant primarily produces electricity that will be used to satisfy the airports' electricity need. The natural gas powerplant generates a significant amount of heat which can then be harvested and used to satisfy air conditioning demand through the adoption of hot water driven absorption chillers and water heating demands (Fig. 19). Table 9 shows the airport integration strategies for ORTIA, CTIA and KSIA.

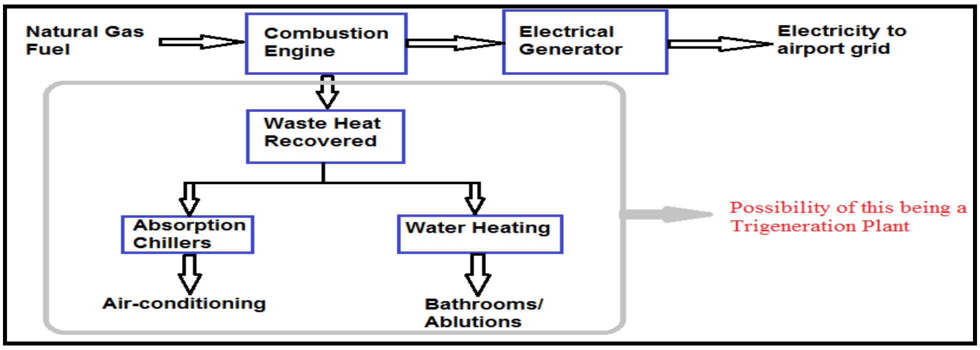


Figure 19: Natural Gas Power Plant Configuration with the Possibility of Waste Heat Recovery for Trigeneration.

Table 9: Suggested Integration Strategy of Natural gas Trigeneration for ORTIA, CTIA, KSIA

Generation Component of the Natural Gas Trigeneration Plant	Suggested Integration Strategy	Required Investigation
Electricity	Provide electricity to the airport's electrical reticulation system as a primary supply with Eskom supply as back up for the rest of the airport's electrical requirement. A smart grid to be employed to coordinate power supply such that the airport receives smooth output of electricity while maximising the cost.	Investigate electricity consumption profile of the airport at various times of the day and during various seasons to secure new notified maximum demand (NMD) from Eskom.
Air conditioning	Absorption chillers to be employed that utilise waste heat from the natural gas engines to produced chilled water for distribution to the air handling units. Prior to distribution of chilled water to air handling units, there should be a buffer chilled water storage tank. Chilled water should be utilised from the absorption chillers primarily. The chillers in the original HVAC plantrooms should be used and cycled as per their cost effectiveness to produce chilled water to make up for any shortfall in production of chilled water. In terms of heating, this should be provided by the absorption chillers primarily. Heaters in air handling units at ORTIA should be disconnected.	Investigate air conditioning demand and how much of this can be satisfied through the absorption chillers; investigate and ascertain piping and instrumentation required for chiller integration.
Hot Water	Hot water to be stored in a hot water tank/s and distributed to the various areas for rest room showers and basins. Should pipe runs result in significant heat loss, this heat loss should be "made up" as per the design with reheat (using, for example, spot heaters for basins and geysers for showers).	Investigate the hot water requirements of the airport and that which can be satisfied from the plant; investigate and ascertain piping and instrumentation required for hot water integration.

Proposed Operational Philosophy

(a) Technical

When the natural gas power plant is running and providing electricity to the airport, the production of chilled water and hot water will be possible. Electricity will be provided as per demand of the airport and running of the generators will be such that it is at optimum capacity for the production of electricity, chilled water and hot water requirements with make-up of electricity requirements being provided by Eskom, with existing chillers and hot water making up shortfalls for air conditioning and water heating requirements.

(b) Plant Operation for Business Continuity and Cost Effectiveness

Plant operation should be designed to run in modular fashion considering the maintenance downtime required. In case of total plant failure either due to technical issues or lack of fuel supply, this should be addressed by business continuity plans that must be put into place before beneficial operation of the plant. This will include memoranda of understanding with various suppliers for alternative fuel supply and capacity required from Eskom in the event of total failure. Guarantees from the plant operators and insurance should also be in place to protect the cost effectiveness of providing electricity to the airport via the natural gas power plants.

(c) Operations and Maintenance

It is proposed that the plant be constructed by ACSA, however, the operations and maintenance should be contracted out as

this is not ACSA's core function nor does the company have the internal skills to operate and maintain this type of plant. With time, the operations and maintenance skills should be transferred to the inhouse team.

CONCLUSIONS

Using natural gas powerplants to serve the baseload and fluctuating energy demands of ORTIA, CTIA and KSIA are feasible. The waste heat harvested from the natural gas engines can be used to serve the airport's space conditioning needs as well as provide for their water heating needs. Natural gas engine technology is a mature technology world-wide, however, not as common in South Africa. Natural gas as a source of fuel has about 50 % of the carbon footprint of the traditional coal-fired power stations. The natural gas power plants will be instrumental in transitioning the three international airports toward a lower carbon footprint, enabling strides toward the airports' agenda of its green star rating through the Green Building Council South Africa (GBCSA) and the Airports Council International (ACI) carbon accreditation. The impact that the natural gas power plants potentially have on the reduction of the carbon footprint of the airports are around 30 % for the ACSA airports. Individually, ORTIA's carbon footprint in electricity consumption will be reduced by about 30 %, CTIA by about 34 % and KSIA by about 48 % by implementing and using natural gas powerplants. To adopt these natural gas powerplants, a final feasibility study (FEL 3) drawn from individual preliminary designs (Front End Engineering Designs or FEED studies) for the airports, together with a detailed risk analysis and legislative requirements including the cost of all requirements must be evaluated against the benefits, so that a financial investment decision can be made.

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